Attachment A. Literature review, prepared September 1993.

Defining Habitat Suitability Criteria for Gravel Bar Mussel Communities: Problems and Considerations of Appropriate Variables

Freshwater mussels (Bivalvia, Unionoida) form a diverse and historically abundant component of the benthic fauna in North American streams and rivers. Numbering about 300 species, mussel abundances and diversity have declined dramatically in recent decades, (Stansbery 1970; Williams et al. 1993). Freshwater mussels live in habitats ranging from small streams to large lakes, but the most diverse assemblages typically occur in riverine shoals or gravel bars, and many species are only found in these large-river habitats (Layzer et al. 1993). Species decline and loss has primarily resulted from deterioration of water quality (from pollution, siltation, surface mining activities) and the actual destruction of river shoals, e.g. by impoundment, dredging, and channelization. Temperature and water quality changes downstream from impoundments are further implicated in population declines and extirpations where physical habitat remains intact (Layzer et al. 1993). Effects of barge traffic include physical damage or destruction of mussels when barges ground on beds, burying or dislodgement of mussels by barge-created turbulence and sediment disturbance, and interference with feeding and reproductive activities (Aldridge et al. 1987; Hubbs et al. 1991). Given the widespread loss of suitable riverine habitat and jeopardy status of the majority of North American mussel species (Williams et al. 1993), identifying and reducing impacts of barge traffic on large-river mussel communities could have large benefits to mussel conservation.

The purpose of defining habitat suitability criteria for riverine mussels is to allow resource managers to address the question: What effect may a specific habitat modification have on mussel communities? In this case, the source of habitat modification is a change in river navigation activities, i.e., the amount, size, frequency and queuing patterns of barge traffic. The Army Corps of Engineers, Louisville District, has developed an analytical model for examining effects of navigation traffic on local current velocities and substrate scour and deposition. Linking this model of physical habitat changes to effects on riverine biota requires criteria that define habitat preferences or tolerances for species of interest. Potential effects on target species may then be estimated on the basis of projected changes in habitat suitability. This report explores the feasibility of constructing criteria for use in predicting how various levels of navigation activities may affect abundance and persistence of riverine mussels.

Habitat Preferences by Riverine Mussels

Riverine and stream-dwelling mussels generally appear to occupy a variety of habitat conditions. Strayer (1981) examined microhabitat characteristics at locations of mussels during low flow conditions in Michigan streams and found that most species occupied a wide range of the available habitat conditions at a given site. In addition, average conditions used by individual species varied among sites, further indicating that species tolerate a broad range of microhabitats. Similarly, Holland-Bartels (1990) reported that mussels occurred over the full range of current velocities and sediment types available in Navigation Pool 10, upper Mississippi River. Species-specific preferences generally included 30-50% of the conditions available during low and high flows. These two studies suggest that many mussel species tolerate broad ranges of current velocity and sediment type, and Strayer and Ralley (1993) recently demonstrated the limited utility of these microhabitat variables in predicting mussel occurrence or density in quadrat samples taken in a New York stream. Similarly, Gordon and Layzer (1989) gave species accounts for mussels known from the Cumberland River system and included general descriptions of habitat-use. Over 50% of 83 extant taxa in the Cumberland occur over a wide range of substrates (i.e., mud to gravel or coarser particles) and velocity (e.g., calm to swift currents). Of the species known from a narrower range of habitats, most (22 species) usually occur in riffles or shoals with sand, gravel and cobble substrates and moderate to swift currents. Restriction to particular microhabitats appears relatively uncommon for unionids.

Broad tolerances would certainly be advantageous to animals with restricted mobility inhabiting fluctuating lotic environments (Tevesz and McCall 1979, Gordon and Layzer 1989). However, although freshwater mussels have been the subject of numerous studies during the past century, quantitative data describing habitat use are relatively scarce (Gordon and Layzer 1989). Furthermore, studies of habitat use relative to available conditions at isolated points in time do not address the possibility that mussels may become habitat limited at particular stream flows, or during particular life-stages.

Habitat conditions may become limiting to mussels during high flows when benthic substrates may be displaced. Payne et al. (1989), studied age class composition of the introduced Asian clam *Corbicula fluminea* in Mississippi streams following especially severe winter and spring floods. The authors also noted that native unionids had only persisted in locations with stable substrates, e.g. "gravelly sand or sand shoals...stabilized by trunks of fallen trees or stands of the submersed macrophyte *Vallisineria* sp." In contrast, Leff et al. (1990) reported higher densities of *Elliptio complanata* in sand or sand and muck than in sand and gravel substrates in a small South Carolina coastal plain stream. However, the highest *Elliptio* densities also occurred in areas with log debris dams and submerged macrophytes, i.e., areas with potentially stabilized substrates. Similarly, unionids in a medium-sized Ontario river most often occurred in low velocity, shallow areas with vegetation and relatively coarse substrate (Salmon and Green 1983). Salmon and Green hypothesized that this represented a compromise between preference for shallow, slow areas (which usually have sand and gravel substrates) and the greater stability afforded by cobble substrate during high flows. Substrate stability and protection from scour appear to be major determinants of habitat suitability for riverine unionids (Kat 1982, Miller 1988, Payne et al. 1989, Holland-Bartels 1990).

Habitat suitability for mussels also depends on the potential at a given site for recruitment of juveniles, by way of glochidia settlement. Miller (1988) attributed the high mussel density and species richness found near wing dams in Pool 7 of the Mississippi River to the combination of depositional currents in areas with stable substrates. Way et al. (1989) compared mussel densities at two inshore (31 m from shore) and two offshore (61 m from shore) sites, approx. 6 km downstream from Kentucky Lock and Dam on the Tennessee River. Species richness (15 to 18 species total) was similar at the inshore and offshore sites, but mussel densities were greater inshore. The inshore sites also had higher sedimentation rates over a two-week measurement period, and Way et al. concluded that "the distribution and abundance of many species of mussels is at least partly dependent upon low water velocities and low to moderate levels of sedimentation for the successful settlement of glochidia".

Substrate and current conditions may also influence habitat suitability for mussels through effects on food availability and feeding efficiency. Kat (1982) documented higher in situ growth rates of larger *E. complanata* located in gravel-sand-clay substrates as compared to individuals placed in mud-clay substrates, although small individuals recruited to both types of substrates. This study implies that although a species may occupy a variety of substrates, some areas may better support growth or reproduction. Because mussels are filter-feeders, they may be particularly susceptible to excessive sedimentation that could both bury individuals and reduce their feeding efficiency. Hartfield and Rummel (1985) found the richest mussel fauna in Big Black River, a Mississippi coastal plain stream, in riffles and runs with gravel substrates as opposed to silt or mud areas, perhaps reflecting intolerance by some species for excessive silt. Aldridge et al. (1987) found that mussels subjected to high levels of suspended solids and turbulence at frequent intervals had lower feeding rates and relied more on body stores to meet metabolic requirements, than mussels subjected only to turbulence, or to turbulence and suspended solids less frequently. Holland-Bartels (1990) also cited sedimentation as potentially degrading to habitat suitability for upper Mississippi river mussels, and found significantly lower abundances of some species in silt and clay as compared to sand substrates.

In summary, substrate conditions and water velocities are primary factors influencing habitat suitability for riverine mussels. Mussels require sufficient substrate stability to avoid displacement during high flows, and sufficient flow to deliver food. Current velocities must be low enough to permit juvenile settlement during appropriate times of the year. However, deposition of excessive fine-sediments may in interfere with feeding.

Habitat Requirements for Successful Reproduction

Reproduction may represent the most vulnerable phase of mussel life-histories to habitat alteration or disturbance. As discussed above, recruited individuals may tolerate a relatively wide range of microhabitat conditions (e.g., reflecting adaptation to flow fluctuations typically experienced in streams). However, for successful reproduction, most unionids require 1) suitable conditions for spawning, 2) that glochidia are able to attach to suitable host fish within a few days of release (Neves and Widlak 1988) and, as discussed above, 3) that following encystment and metamorphosis on the host, juveniles are able to settle in suitable habitat.

A study by Payne and Miller (1989) provided evidence of the potential year to year variability in reproductive success that may be common in riverine unionids. Payne and Miller reported recruitment of a single dominant cohort of *Fusconaia ebena* in a six-year period, in a gravel shoal in the Ohio River downstream of Lock and Dam 53. *F. ebena* is a dominant species in gravel shoal mussel assemblages in the lower Ohio River and Tennessee River. This study showed that the 1981 cohort of *F. ebena* numerically dominated the population through at least 1987, with low levels of recruitment in years after 1981. After recruiting, the cohort had low annual mortality. Although we do not have extensive population data for other riverine unionid populations, strong among year variation in reproductive success may commonly occur in long-lived, riverine mussels. In any case, mussels clearly require some specific conditions for successful reproduction, and populations will be vulnerable to habitat changes that result in repeated reproductive failure.

Current velocities may influence reproductive success through effects on fertilization and, possibly, premature glochidia abortion. Successful spawning by mussels may partly depend on low current velocities at the time of sperm release (Zale and Neves 1982a). Prolonged high flow rates or turbulence could interfere with fertilization, which may oc̦cur over a large portion of the spring and summer within a mussel assemblage. Zale and Neves (1982a) reported that four co-occurring Lampsiline species spawned over short periods (two weeks or less), but at distinctly different times in July and August. Other species spawn over variable periods during spring or early summer (Yokley 1972, Yeager and Neves 1986, Neves and Widlak 1988, Gordon and Layzer 1989); one species is known to spawn biannually (Gordon and Layzer 1989). After spawning, females may prematurely abort glochidia if disturbed (Yokley 1972, Yeager and Neves 1986, Gordon and Layzer 1989). The time required for glochidial maturation varies among species (e.g., 4 - 6 weeks for *Pleurobema cordatum*, Yokley 1972; 7 - 8 weeks in four Lampsiline species, Zale and Neves, 1982a), and may depend on water temperature (Yokley 1972). Further, species vary in length of time that glochidia are retained in the gills prior to releasing; long-term brooding species retain glochidia through the winter, whereas short-term brooders release glochidia soon after the glochidia complete development (usually in the summer). Gordon and Layzer (1989) review intraspecific and interfamilial variation in brooding periods. From the aspect of defining habitat suitability for mussels, it is significant that even closely related species within an assemblage vary in the time periods over which females may be vulnerable to disturbances, possibly including strong turbulence, that would cause premature glochidia release.

Glochidia release must coincide with the presence of appropriate hosts (usually fish) for mussels to successfully reproduce. Thus, habitat conditions near mussels must be suitable for the host fishes during the time when glochidia are released. However, as for spawning, the timing of glochidia release may greatly vary among co-occurring mussel species. Neves and Widlak (1988) observed non-synchronous release of glochidia throughout the year by (winter brooding) Lampsilinae species, with release peaking in April and mid-June to mid-July. Summer brooding Ambleminae species released glochidia from June to mid-August (Neves and Widlak 1988). Species-specific timing of glochidia release may correspond to periods when fish hosts are most likely to be present. Zale and Neves (1982a, 1982b) compared glochidia release patterns among four Lampsiline species, all long-term (winter) brooders, in Big Moccasin Creek, VA. *Medionidus conradicus* released glochidia nearly year-round, and its fish hosts, *Etheostoma rufilineatum* and *E. flabellare* also inhabited riffles year-round, and thus were continuously available. In contrast, two species (*Villosa nebulosa* and *Lampsilis fasciola*) that parasitized centrarchid fishes released glochidia in late spring and summer, when centrarchids also occurred in riffles over mussel beds. Finally, *V. vanuxeni* released glochidia in fall and winter, concurrently with presence of its host, *Cottus carolinae*.

Consideration of factors necessary for successful reproduction emphasizes the close link between habitat suitability for mussels and that for their host fish species. Yokley (1972) attributed low recruitment of *Pleurobema cordatum*, a species widely distributed in mussel beds of the Tennessee River and Ohio River system, to loss of appropriate habitat for its host, *Lythrurus ardens*, as a result of impoundments on the Tennessee River. Local microhabitat conditions also influence habitat use patterns by fishes, and thus indirectly, habitat suitability for mussels. For example, Yeager and Neves (1986) demonstrated that three species of cyprinid (minnow) fishes were suitable hosts for *Quadrula cylindrica strigillata* in the upper Tennessee River drainage. Adult *Quadrula* most often occurred "in eddies and along the periphery of midstream currents", areas also favorable for foraging by drift-feeding cyprinids. Mussels were not found in microhabitats less suitable for foraging minnows, e.g. areas with either high current velocity or stagnant water. Somewhat similarly, Cvancara et al. (1966) noted that *Lampsilis siliquoidea* appeared concentrated along the thalweg of a small North Dakota stream, in areas with relatively high velocity and pebble-gravel or gravelly sand substrate. This is one of the few reports of local habitat specificity by a unionid, and is for a species that occurs in lakes and streams, in mud as well as sand and gravel (Gordon and Layzer 1989, Cummings and Mayer 1992). Habitat specificity by this mussel species in the North Dakota stream may reflect habitat-use patterns by its host fish.

Generalizing Criteria for Species Assemblages

The high species richness that characterizes riverine mussel assemblages greatly complicates attempts to analyze effects of habitat changes on a species by species basis. As many as twenty, or more, mussel species may coexist at a given large-river location (Van der Schalie 1939; Dycus and Jenkinson 1983; Miller et al. 1986; Holland-Bartels 1990). Generalizing the effects of habitat alteration to groups of species or to entire mussel assemblages, rather than estimating effects on individual species, offers obvious analytical advantages. Whether or not species can validly be pooled depends on the similarity among species in their habitat requirements and sensitivity to alterations.

Studies comparing microhabitat use by coexisting mussel species indicate broad overlap among species. Strayer (1981) and Holland-Bartels (1990) noted few interspecific differences in microhabitats occupied by mussels. Similarly, Miller et al. (1986) found no distinction between the habitat occupied by *Plethobasus cooperianus*, which is Federally listed as endangered, and other unionid species inhabiting an Ohio River mussel bed. In contrast, Salmon and Green (1983) were able to array seven unionid species along a multivariate axis describing differences in habitat use in an Ontario river. We probably know too little about species-specific habitat preferences to assess fully the extent of habitat segregation within mussel assemblages. However, even if the species inhabiting large river shoals have similar habitat requirements as adults, species likely differ in the timing of spawning and release of glochidia, and in habitat requirements of their host fishes. Therefore, generalized criteria for reproduction would necessarily apply to an extended period in order to accommodate differences among species in timing. Habitat requirements for host fishes (if indeed both the fish species and their requirements are known) could be applied to those months when the appropriate fishes normally occupied shoals. For some fishes that serve as mussel hosts, this may be a large portion of the year.

Considerations for Developing Habitat Suitability Criteria for Unionids

Generalized habitat suitability models for large-river mussels would take a different form than most species-specific models. It appears unlikely that suitabilities can be assigned to specific ranges of depth, velocity or substrate size, either for particular species or for species assemblages. First, velocity and substrate appear interdependent in influencing suitability by jointly determining substrate stability. Secondly, local current velocities must be low enough during periods of juvenile recruitment to permit young mussels to settle. This period would depend on local species composition, given among-species differences in when glochidia are released, but could include a large portion of the year. Similarly, conditions for host fish must be included in models of mussel habitat suitability, at least for periods of glochidia release. Ultimately, of course, suitable habitat must be available for all life-stages of the host fishes to insure mussel reproduction. Thus, habitat alteration may affect mussels as much by influencing certain fish populations as by directly affecting mussel habitat.

The following components appear necessary for defining habitat suitability for large-river mussels affected by navigation activities:

1. Substrate stability: a useful approach may be to estimate the likelihood of substrate displacement given substrate size and current velocities near the bottom, under alternative barge-traffic scenarios. Habitat suitability would decline with increasing probability of substrate movement.

2. Turbulent currents: surges in current insufficient to displace the substrate may be strong enough to interfere with mussel feeding, juvenile settlement, or host fish activities. Turbulence near the bottom should be evaluated under alternative traffic scenarios and related to effects on, at least, juvenile settlement and host fish during appropriate time periods.

3. Sedimentation rates: excessive sedimentation will likely reduce habitat suitability for mussels. Changes in sediment suspension or deposition as a result of navigation activities should be explicitly considered.

4. Habitat suitability for host fishes: at a minimum, habitat conditions relative to known host fishes should be incorporated in models of habitat suitability for mussels, at least for time periods when glochidia are released.

These components are based on habitat effects on mussels as described in the literature, discussed above. Much of this material concerns mussels in streams and smaller rivers. Designing habitat criteria specifically for mussels inhabiting large-river shoals could first involve developing a list of the mussel species most likely to form assemblages in the river systems of interest, and for those mussels, listing host fishes, spawning periods, and glochidia release periods in so far as is known. The following approach outlines a starting point for developing habitat suitability criteria.

- Assuming gravel-cobble shoals are the primary habitat type for the assemblages of interest, then suitability in terms of "substrate stability" could be described by probability of substrate displacement, as a function of near-bottom velocity. Habitat suitability would be highest in shoal areas with the most stable substrates during normally high flow periods. Velocity surges sufficient to displace substrate would reduce habitat suitability at a particular point.

- The effects of smaller velocity changes associated with barge traffic should be evaluated in terms of the question "How much turbulence (or sediment suspension and resettlement) can mussels withstand?".

- Shoal areas normally having slow or eddying currents may serve as settlement areas for juveniles; in this case, velocity surges over a low threshold level could significantly reduce the suitability of these areas for juveniles.

- Curves specifying foraging-habitat suitability for known host fishes could be applied to shoals for that portion of the year when glochidia are likely to be released, and when metamorphosed juveniles leave the host.

Developing criteria for mussels might best be accomplished through deliberation among biologists with expertise in mussel ecology. The above discussion outlines a possible starting point; other critical variables may become evident through consultation with mussel experts.

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